



universität
wien

DIPLOMARBEIT

Titel der Diplomarbeit

"No Inhibition of Return after Color Singletons in Manual and Saccadic Responses"

verfasst von

David Schwenen

angestrebter akademischer Grad

Magister der Naturwissenschaften (Mag.rer.nat)

Wien, 2014

Studienkennzahl lt. Studienblatt: A 298

Studienrichtung lt. Studienblatt: Diplomstudium Psychologie

Betreut von: Univ.-Prof. Dr. Ulrich Ansorge

für
Sara

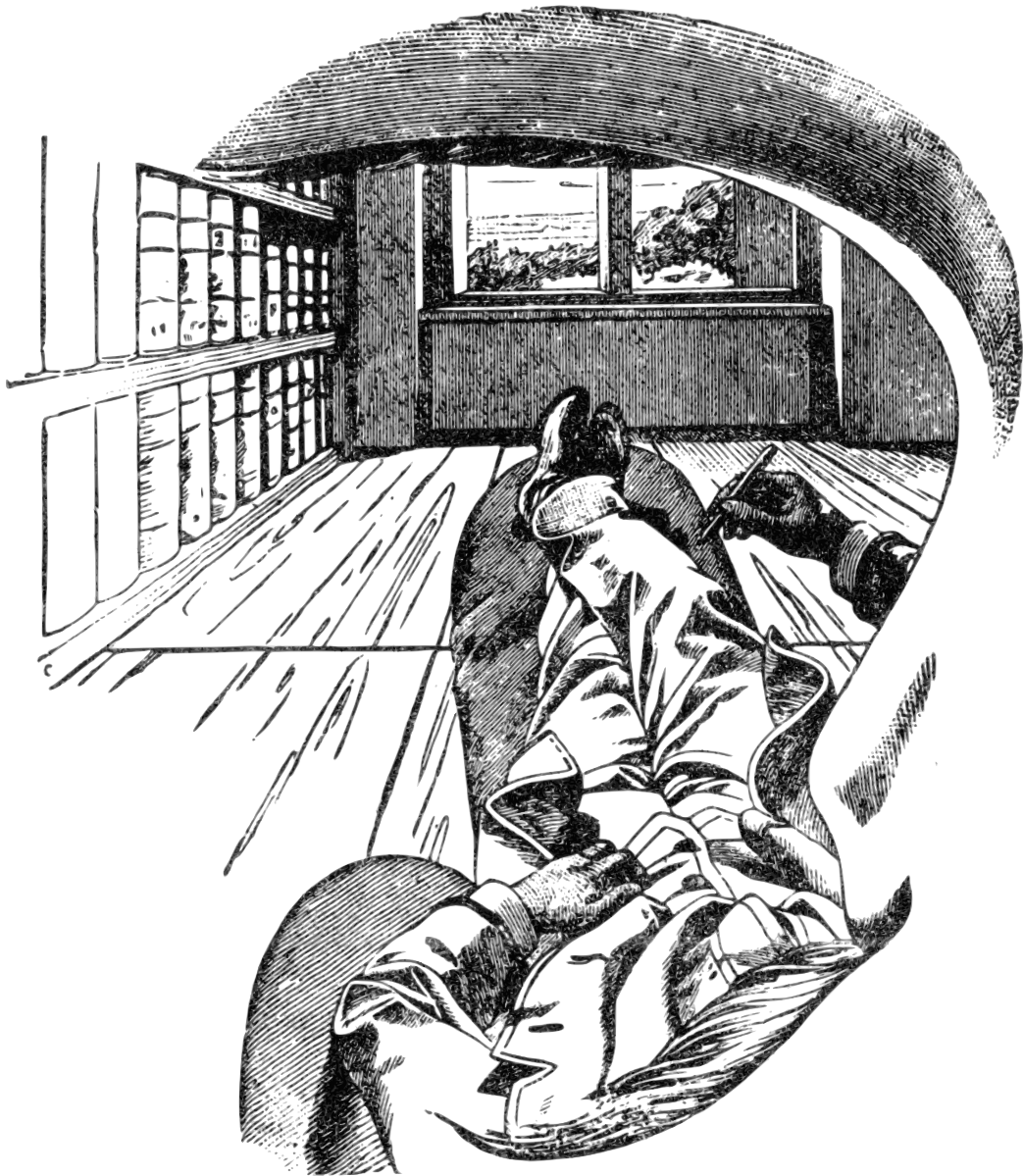
Danksagung

Zu Beginn möchte ich all jenen danken die mich beim Erstellen der vorliegenden Arbeit mittelbar und unmittelbar unterstützt haben. Der größte Dank gebührt meinen Eltern, welche mir das Psychologiestudium und auch sonst buchstäblich alles ermöglicht haben. Außerdem bedanke ich mich herzlich bei meiner wunderbaren Freundin Sara die mir, obwohl ich in den letzten Monaten aufgrund der Arbeit viel zu wenig Zeit für sie hatte, stets mit Geduld, Humor und Optimismus zur Seite gestanden ist.

Ein großer Dank geht außerdem an Ulrich Ansorge der es geschafft hat mit wissenschaftlicher Neugier und Ehrgeiz, sowie mit seinem vorbildhaften Verhalten in Sachen good-scientific-practice mein Interesse an visueller Aufmerksamkeit und psychologischer Forschung im Allgemeinen neu zu entflammen und mir dabei stets mit Rat und Tat zur Seite stand. Ebenso danke ich Heinz-Werner Priess der mir während der Datenerhebung und dem Debuggen der von ihm zur Verfügung gestellten Experimentalsoftware, sowie durch seine kompetenten und in der Regel ausführlichen Erläuterungen in der frühen Phase der Bearbeitung meiner Fragestellung unschätzbare Dienste geleistet hat.

Desweiteren geht mein Dank an alle meine Freunde in der Heimat und in Wien denen ich besonders in den letzten Monaten der Erstellung der Abschlussarbeit leider viel zu wenig Zeit widmen konnte und die mir mein "Abtauchen" hoffentlich nachsehen. Nicht zuletzt gebührt mein Dank dem österreichischen Staat und der europäischen Union die mir das Studium ermöglicht haben welches mir in meinem Heimatland, sofern überhaupt, nur mit ausserordentlich langen Wartezeiten möglich gewesen wäre.

Danke!



Innenperspektive. Adapted from "*Die Analyse der Empfindungen und das Verhältnis des Physischen zum Psychischen*" (p. 15), by Ernst Mach, 1903, Jena: Gustav Fischer Verlag. Copyright expired.

Abstract

Inhibition of return (IOR) has been suggested to be a hallmark of involuntary attentional capture by highly salient non-predictive peripheral cues. While many studies have found IOR after onset cues, experimental results regarding IOR after color singleton cues have been mixed. The examination conducted for this thesis was aimed at answering the question, whether in those studies that did not find IOR after color singleton cues, peculiarities of the experimental procedure have been responsible for the absence. In a first experiment a variation of the spatial cueing paradigm was used to replicate the finding of an absence of IOR after color singletons in a discrimination task based on keypress responses (Gibson & Amelio, 2000). After successful replication the same procedure and stimulus material was used, to test whether a change to the presumably more IOR sensitive saccadic response mode and a detection task would unveil otherwise hidden IOR. This was not the case. Possible explanations for this finding as well as limitations of the experiments are discussed. Finally implications for the debate about the influence of attention on early visual processing are pointed out and suggestions for future studies are made.

Keywords: inhibition of return, manual responses, saccadic responses

Contents

No IOR after Color Singletons in Manual and Saccadic Responses	7
A Brief Introduction to Spatial Orienting of Visual Attention	8
Inhibition of Return	16
Objectives of the Present Study	19
Methods	23
Procedure and Design	23
Apparatus and Stimuli	26
Participants	27
Results	29
Data Preparation	29
Results of the Manual Response Experiment	30
Results of the Saccadic Response Experiment	33
Discussion	41
General Discussion	41
Limitations of the Current Experiment	45
Implications for Future Research	48
References	49

No IOR after Color Singletons in Manual and Saccadic Responses

This thesis is concerned with the effects of manual and saccadic response modes on the performance related costs and benefits of color defined peripheral singleton cues. For the naive reader all these terms used in the title and first sentence may seem cryptic, therefore I will begin with an easy to comprehend example: Imagine you are worried because you haven't seen your beloved, old and deaf pet for a while, therefore you start searching for it. Because you have been living with your pet for some years and know its habits, you decide to begin your search at its favorite places, that is, you use knowledge about the object of your search for constraining the search space. During your search you may have checked out his first two favorite places and go on looking in the other two, that is, you benefit from knowing where you have been looking before by not having to search the same places over and over again. If you understand the usefulness of both described strategies it's not only likely that you will find your beloved one sleeping in the sun on a chair at your terrace, but at the same time you have understood a lot about the questions this thesis deals with.

In visual search (think of "Where's Wally?") both constraints (foreknowledge and a track record of already searched locations) have the potential to provide benefits for search performance. However there is a debate in the scientific community about when these constraints are in fact used in simple tasks like visual search to guide one's focus of attention. In a specific study (Gibson & Amelio, 2000) the authors found that when searching for color stimuli, foreknowledge can be used to guide search (by attentional modulation of early visual processing) but they failed to find inhibition of return (IOR; which is often seen as based on a track record of visited locations). The experiment conducted for this thesis aims at contributing to a better understanding of early visual processing by testing whether Gibson and Amelio's results can be replicated or were, as suggested by some authors (Godijn & Theeuwes, 2004), caused by peculiarities of their design. Selective attention's central role in the human mind makes understanding its influence on early visual processing crucial for a variety of different scientific disciplines (e.g. cognitive science, robotics) and many practical applications (e.g. optimization of visual presentation, search algorithms).

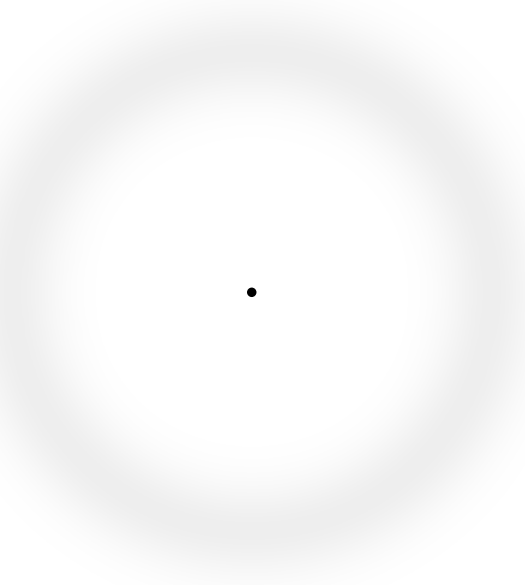


Figure 1. The Troxler effect. To experience sensory adaptation at first-hand, try to completely focus your view on the dot in the middle of the blurred circle and note how after a few seconds the circle seems to disappear. Notice also how it reappears immediately at the slightest movement of the eye. Sensory adaptation is believed to be the result of the big size of extrafoveal receptive fields of the retina. Adapted from “*Box 1*” by Martinez-Conde, Macknik, & Hubel, 2004.

A Brief Introduction to Spatial Orienting of Visual Attention

Although most of the time we are not aware of it, our eyes are moving constantly in varying amplitudes and frequencies (for an introduction see Rayner & Castelhana, 2007). The larger fixational eye movements called saccades (see Walker, 2012) appear with a frequency of about three till four per second, rendering our extraocular muscles the most often activated muscles in our body. The localization of food or threats in the environment, in fact the ability to perceive any visual information, depends heavily on movements of the eyes. If in experimental settings the retinal image is fully stabilized (e.g. by an optical apparatus or drug induced deactivation of our eye muscles; both very unnatural conditions) it takes only a few seconds for the perceptual image to fade and disappear completely as a result of sensory adaptation (e.g. Riggs, Ratliff, Cornsweet, & Cornsweet, 1953; Martinez-Conde, Macknik, & Hubel, 2004; see figure 1). The anatomy of the retina (see Dowling, 2007) further requires

us to move our eyes in order to be able to perceive objects surrounding us in detail. High resolution vision is enabled by specialized cells called cones in a part of the retina called the fovea which makes up a very small proportion of the overall retina. Therefore only in a tiny cutout of our visual field we are able to perceive the world in detail. One of the most important questions in the science of vision is consequentially “How is the location of the next eye movement selected?”.

Covert orienting. It’s intuitively evident that there is a close relation between movements of the eyes and our spatial visual attention. Usually what we look at is what our visual attention is directed at, however as was initially documented by Hermann von Helmholtz (1896) this doesn’t have to be the case all the time. Covert spatial orienting of visual attention happens in contrast to overt spatial orienting without easily observable eye movements. Instead it can be studied by taking precise performance measures (e.g. reaction times, RT, or measures of error rates, ER) in experimental settings (Posner, 1980). According to the today widely accepted Premotor theory (e.g. Rizzolatti & Craighero, 2010) of visual orienting, covert spatial orienting of attention precedes eye movements, that is covert orienting serves the purpose of the preparation of saccades to certain locations in space. It can therefore be seen as a form of orienting by mental focus. A critical structure in the deployment of spatial attention and the location planning of eye movements are the superior colliculi (SC) situated in the brainstem (Krauzlis, Lovejoy, & Zenon, 2013). Those structures integrate inputs from many cortical and subcortical areas as well as the retina and generate retinotopic location signals which activate further oculomotor parts of the brainstem and ultimately result in a saccade to the area in the visual field corresponding to the locus of the most activity. SC activity seems to also influence information transmission between retina and visuocortical areas by changing information transmission in the thalamic lateral geniculate nuclei (LGN). This may happen by direct connections to magnocellular LGN layers and indirect connections via the pulvinar to parvocellular LGN layers. This influence might be responsible for part of the effects observed in investigations of covert spatial orienting, as neuroscientific methods can show (e.g. Lovejoy & Krauzlis, 2010).

Saliency. One important influence on the direction of the next eye movement are the properties of the elements making up the visual scene we are inspecting. While retinal cells react to very simple physical properties of the light falling onto them (such as its intensity, wavelength, and its tempo- and spatio-structural properties), after a transmission of retinal cell activity via the thalamic LGN, specialized tissue in visual cortical areas reacts to (or extracts) the basic survival-relevant perceptual features of objects in visual scenes (such as motion, color, orientation and size, for a review of features see Wolfe & Horowitz, 2004). In both retinal- and retinotopically-organized cortical tissues competitive interactions of mutual inhibition between neurons within receptive fields (see Alonso & Chen, 2009), play a decisive role in the outcome of their activity dynamics (see e.g. Beck & Kastner, 2007). The outcome of these interactive dynamics in the different feature receptive areas can be imagined to result in a comprehensive “map” which represents the amount of attentional attractiveness, conspicuity, or saliency (see Itti & Koch, 2000; Itti, 2007) of all locations in the inspected visual scene (whether such a map physically exists is not yet agreed on; see Niebur, 2007).

Visual search. A lot of the information known about saliency stems from experiments on visual search (see e.g. Eckstein, 2011; Wolfe & Horowitz, 2008). In visual search subjects typically have to find a target object among a set of distractors. The efficiency of search (measured in RTs and ERs) is influenced by a variety of factors like similarity relations of targets and distractors, spatial layout of objects (density and crowding), search history (like in priming, cueing, or IOR), item size and number of distractors (see Wolfe & Horowitz, 2008). For example the most easy to find targets (called singletons or feature-singletons) are usually defined by a unique (in the display) feature value and presented among a set of dissimilar, but among each other homogeneous, distractors. Under these conditions of high feature contrast, saliency computations in visual cortical areas result in one highly salient target (for example an **E**) which perceptually “pops out” of its environment (see figure 2a, left) and therefore requires very little (if any) search time, irrespective of the number of distractors (see figure 2a, middle: Singleton target). In contrast, non unique targets, which

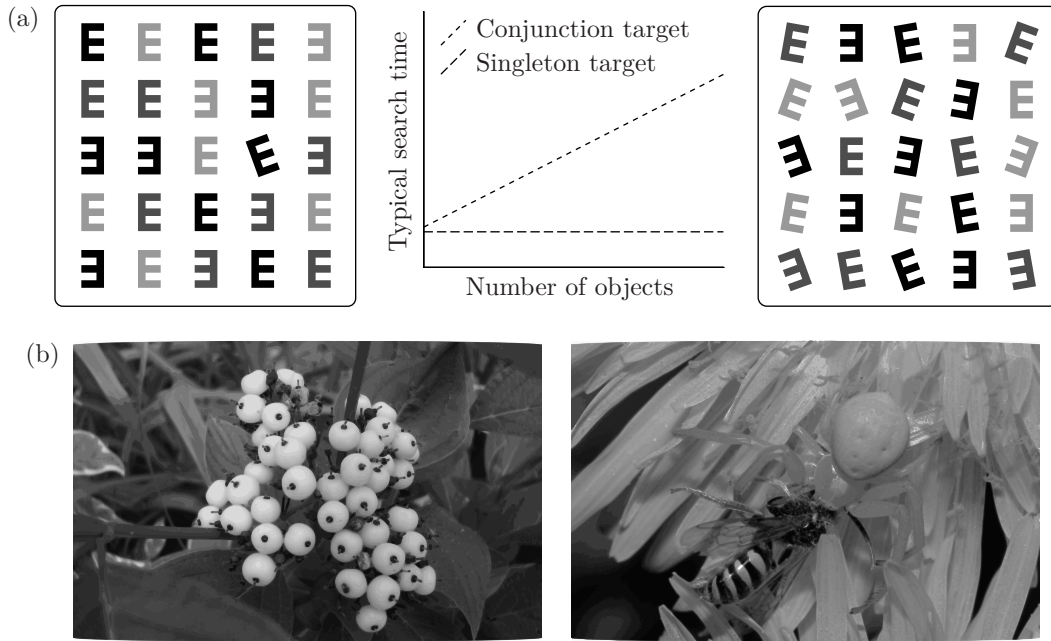


Figure 2. Illustration of feature contrast in experimental (a) and natural stimuli (b). (a) left: Feature contrast makes basic-feature singletons “pop out”. middle: Simplified search slopes for singleton and combined-feature targets as a function of set size. right: Combined targets are more difficult to spot because search can not be efficiently guided. (b) left: Fruit often attract attention by local feature contrast. right: *Misumena vatia* spiders hide from predators and prey by imitating the color of their surroundings. (b) Adapted from "*Cornus sericea 'Baileyi'*", by The County Clerk, 2009, retrieved from <http://www.fotopedia.com/items/flickr-2643651215>. & "*Misumena vatia* with wasp", by Olaf Leillinger, 1998, retrieved from <https://commons.wikimedia.org/wiki/File:Misumena.vatia.beute.wespe.1771.jpg>. Copyright for both pictures: CC BY-SA 2.0.

are defined by a combination (also called conjunction) of different features in the display (again e.g. an **E**; search for it in figure 2a, right), presented among a set of non-homogeneous distractors are increasingly difficult to find as the number of distractors rises (see 2a, middle: Conjunction target). In this case feature contrast can not be used to guide search in a fast and “automatic” way because the number of similar objects in the search display reduces the salience of each individual object and also of the searched for target. Therefore search has to be performed in a serial manner. Since saliency computations are mainly (but likely not solely; see below) influenced by properties of the stimuli present in the visual field and can be carried out in parallel (i.e. fast), the stimulus driven influence of salience on attentional orienting is often considered to be automatic, reflexive, involuntary, or bottom-up.

Bottom-up orienting. One line of research spearheaded by a group surrounding Jan Theeuwes has used visual search experiments (the additional singleton paradigm) to demonstrate that salient distractors can not be ignored, regardless of the intention of a subject (Theeuwes, 1992; Theeuwes, 2004). Theeuwes and colleagues have repeatedly shown, that the presence of singletons in a search display which are more salient than the searched for target, results in a RT and accuracy cost, that is, subjects respond significantly slower and with less accuracy to search displays that include highly salient distractor stimuli compared to search displays that don't. The authors have drawn the conclusion, that speed and accuracy of visual search depend heavily on salience computations and that the initial orienting of attention is not influenced by search goals of the observer. In their view the performance in visual search mainly depends on an initial "feed-forward sweep" of saliency computations which directs (covert) visual attention across the stimulus display. Only after this initial orienting higher order (top-down) cognitive processes decide whether the salient object which captured attention is the searched for target or not and subsequently trigger a response or disengage/deallocate attention to continue searching (e.g. Theeuwes, 1994). If a target stimulus does not pop-out but requires serial search, the authors argue that the spatial attentional window (which in pop-out search is spread over the entire display) is more narrow and therefore needs to be moved across the visual display, but that inside of the attentional window search performance is nevertheless based only on purely stimulus driven saliency computations (e.g. Belopolsky & Theeuwes, 2010).

Although some experimental results corroborate the view of limited influence of attention in visual search (e.g. Stigchel et al., 2009; Theeuwes & Van der Burg, 2011) and it is the foundation of influential computational models of attentional orienting (e.g. Itti & Koch, 2000) it represents only one side of an ongoing debate in the field. The next sections first present a different paradigm and then a view which suggests a much more influential role for top-down or high-level components of attention (i.e. functions higher in the cognitive processing hierarchy) and is favored by the majority of researchers (for an illustration of one kind of effect top-down modulation can have on visual perception see figure 3).

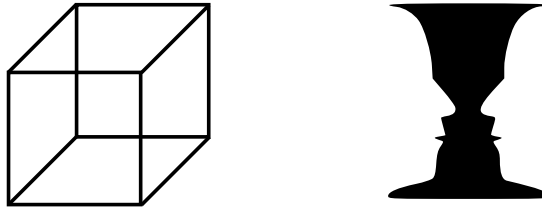


Figure 3. Multistability can serve as an example of top-down modulation of visual perception. The left form (a Necker cube) can be perceived as the black edges of a cube in two different spatial configurations. The right form (based on Rubin’s vase-illusion) can either be perceived as the outline of a vase or the outline of two faces oriented towards each other. By focusing on different aspects of the depictions we can voluntarily change what we perceive. From “*Multistability*”, by Alan De Smet, 2007, retrieved from <https://en.wikipedia.org/wiki/File:Multistability.svg>. Copyright: Public domain.

The spatial cueing paradigm. While in the visual search paradigm often static displays are used, the spatial cueing paradigm (Posner, 1980; see also Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014) allows to investigate the timecourse of attentional orienting by presenting a sequence of events. In this experimental procedure subjects face a central fixation cross on which they have to keep their view focused throughout a trial, as well as the subsequent presentation of a cue-stimulus (which requires no response and is often instructed to be ignored) and a target-stimulus (to which a response is to be made) in the periphery of the visual field (if involuntary capture is the primary interest). The cue can appear at the same position as the subsequent target (it is then called a valid cue) or at a different position (an invalid cue), which allows for the computation of so called validity effects. Generally in trials with a short cue-target-onset-asynchrony (CTOA) and valid cues, RTs are faster compared to those in trials with invalid cues. This is usually interpreted as a sign of attentional capture by the cue, as it is seen as the result of a shift of covert attention to the cue’s location which facilitates processing of the subsequently appearing target stimulus. If a cue is highly salient this shift of covert attention happens although subjects are instructed to ignore the cue and importantly even when the cue’s location is unpredictable of the location of the later appearing target stimulus. This result alone is therefore in line with the bottom-up account of attentional orienting since it indicates that the cue overrides the intention of the subjects and leads to involuntary orienting.

Feature based orienting. Importantly in an influential study Folk, Remington, and Johnston (1992) were able to show that cues are only able to capture attention when they match the features of a target (either the targets feature dimension or the feature value; see Folk & Remington, 1998). These results indicate that saliency can be used in visual orienting tasks in a goal directed fashion, that is, the goals of a subject are contrary to the assumptions of the pure-capture account able to influence attentional orienting even in early processing stages. In their explanation of these results Folk et al. suggest that the observers search goals influence performance by an attentional set which instantiates the search goals. Since capture depends according to this view on the attentional control settings instantiated in order to fulfill the task, Folk et al.'s theory is called the contingent capture account of attentional orienting in the literature. Because the attentional set is based on influencing the perceptual and behavioral consequences of specific features it's an instance of feature based attention. A neurophysiological explanation of the underlying mechanisms involved in influencing salience computations in a top-down fashion has been presented in form of the biased competition theory by Desimone and Duncan (1995; see also Gilbert & Li, 2013; Ruff, 2013). A number of studies have found results which match the predictions of the contingent capture account (e.g. Ansorge & Heumann, 2003; Lamy, Leber, & Egeth, 2004; Wyble, Folk, & Potter, 2013; for a review see Burnham, 2007) and it has served as the basis for other theories about top-down attentional influences on early visual perception, it is however incompatible with the bottom-up account of Theeuwes and colleagues (for overviews see e.g. Egeth, Leonard, & Leber, 2010; Folk & Remington, 2006; Theeuwes, 2010).

Explanations for differing experimental evidence. Every good theory of visual selective attention should be able to explain both types of results, those acquired in the additional singleton paradigm as well as those from the spatial cueing paradigm. Therefore supporters of both accounts have come up with alternative explanations for the results interpreted in favor of the other side's point of view. Bacon and Egeth (1994) for example, argued that Theeuwes (1992) original results (the influence of salient singletons on performance despite task irrelevance) could be brought in line with the contingent capture account by

understanding them as being caused by an attentional set for singleton search instead of by pure capture. They argued considering the nature of Theeuwes' task, such a singleton set would be the most simple and efficient way of completing the task. Unfortunately discerning a singleton search mode from salience driven capture is a problem which is hard to solve with experimental methods alone because both have identical behavioral consequences (as pointed out for example by Folk, Remington, & Johnston, 1993). Theeuwes and colleagues on the other hand have argued that the results obtained in line with the contingent capture account (faster RTs and stronger distraction after cues matching features of the target stimulus) could be explained by faster disengagement of attention after irrelevant stimuli, which again would result in almost identical behavioral performance. The authors argue that peculiarities of the experiments using the spatial cueing paradigm, in particular the use of blocked trials in which the same stimulus is repeatedly used as a target, result in faster disengagement after irrelevant cues because memory of the repeated stimulus becomes more accessible and processing as well as rejecting irrelevant stimuli happens more quickly. That is, Theeuwes et al. attribute this adaptation of later processing stages to intertrial priming, an effect of adaptation to information in the environment which is considered (by some) to be happening involuntary (e.g. Theeuwes, 2013; but see Lamy & Kristjánsson, 2013; Leonard & Egeth, 2008).

An ongoing debate. Many aspects have to be considered when trying to find out which side's theoretical explanation is closer to the truth, however for the sake of brevity not all aspects can be discussed here (see the overview articles mentioned on the facing page for more detailed discussions). It can however be stated that answers to the questions surrounding the debate about bottom-up and top-down influences on early processing have not yet settled. Both sides have presented compelling arguments explaining their own as well as the results of the other side. As a consequence Theeuwes and colleagues have broadened the debate by using another attentional effect, that of IOR, to argument in favor of their account. In the next section I will introduce the reader to the topic which was at the center of interest in the experiment carried out for this thesis.

Inhibition of Return

Besides facilitation, the spatial cueing paradigm allows for the examination of a second performance effect called inhibition of return. Initially described in detail by Posner, Rafal, Choate, and Vaughan (1985), IOR is characterized by a reversal of the attentional capture or facilitation pattern (i.e. slower responses after valid spatial cues) that can be observed in validity effects with cue target onset asynchronys (CTOAs) longer than about 200 ms. Posner et al. considered this effect to be (like capture/facilitation) triggered by attentional engagement to the cue, but to rely on a memory representation of the cued location in the attention system which leads to a reduced tendency to revisit already inspected but now attentionally disengaged locations, hence the name inhibition of return (IOR). The functional significance of this process is according to the authors, improved performance in visual search by keeping a record of already visited locations which is subsequently used to guide spatial attention to not yet visited locations. In the context of attentional guidance by saliency this could in static as well as dynamic stimulus environments, via location- and the later discovered object-based IOR (e.g. Tipper, Driver, & Weaver, 1991; Theeuwes, Mathôt, & Grainger, 2014), represent an indispensable mechanism to avoid searching the same salient areas over and over again (e.g. Klein & Ivanoff, 2008). Since IOR can operate in location based as well as object (or environment) based reference frames it seems likely that the phenomenon relies on multiple neuronal substrates but little is known about the exact underlying mechanisms. Importantly the name IOR, coined by interpretations of the very early experiments dealing with this effect implies the described very specific functional role (facilitation of foraging) and mechanism (inhibition after disengagement) and is therefore not theoretically neutral.

Questions regarding the role of IOR in visual search. Later experiments have among other questions tested whether the above presented interpretation of the IOR phenomenon is accurate. There have been some findings in favor of Posner et al.'s foraging hypothesis (e.g. Klein & MacInnes, 1999), but also many others which question this account. For example several studies have cast doubt on the notion that the observed slower reactions

to cued targets are tied to the function of inhibiting return saccades (Hooge, Over, van Wezel, & Frens, 2005; T. J. Smith & Henderson, 2011; Wilming, Harst, Schmidt, & König, 2013). Other researchers have called into question whether for IOR to occur at a specific location attention has first to be oriented towards it and then be disengaged, by showing IOR at still attended to locations (e.g. Lupiáñez et al., 2004; Lupiáñez, Martín-Arévalo, & Chica, 2013). Based on these deviationist findings many alternative theories have suggested mechanisms, which differ from the traditional interpretation, to explain the slower responses in cued trials after long CTOAs. Lupiáñez et al. (2013) have presented an account based on updating object files which they termed the detection cost theory and which, as the name suggests describes IOR as the result of a cost of detecting new information when it is very similar (e.g. by sharing features like color or by being presented on the same position) to previously perceived information. Not necessarily in contradiction to the traditional explanation, Dukewich (2009) explains IOR as caused by a physiologically habituation of the orienting response to cued locations. Wang, Satel, and Klein (2012), have developed an oculomotor explanation which sees short lived asymmetric activation patterns in the SC as responsible for part of the effects observed as IOR. According to Wang et al. the motor component of IOR is complemented by later occurring sensory effects. Moreover the conditions under which IOR occurs have been a topic of interest. Consistent with the traditional account IOR is most often found with peripheral cues and targets (e.g. Chica et al., 2014), suggesting a special role for involuntary orienting in triggering slower responses to cued locations. IOR is also often observed in stronger quantities and earlier in detection versus discrimination tasks (see. e.g. Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997) a result which may be based on the larger cognitive demands in discrimination tasks and seems especially prone to be triggered by onset cues (probably a result of direct influence on the SC via the retinotectal pathway; e.g. Liao & Yeh, 2013). It can be concluded that although the interest in the phenomenon is strong and even rising, there is little agreement at this point about the nature of IOR (e.g. Berlucchi, 2006).

IOR as a hallmark of exogenous capture. Despite these difficulties regarding the precise definition of IOR and the limited understanding of the interplay of different processes potentially contributing to the phenomenon, some authors still find the canonical interpretation of it as a foraging facilitator most convincing and have consequentially treated IOR as being a hallmark of stimulus driven attentional orienting (e.g. Theeuwes & Godijn, 2002; Theeuwes & Van der Stigchel, 2006). They argue that IOR can be observed only after involuntary orienting (e.g. Pratt, Sekuler, & McAuliffe, 2001) and its appearance can therefore be used as evidence that stimulus driven involuntary orienting to the inhibited location must have taken place. Following this logic the presence of IOR in the additional singleton paradigm can then be used to counteract the explanation of attentional capture in the additional singleton paradigm as being caused by an attentional set for singletons. However besides suffering from the currently limited understanding of IOR, this interpretation faces the problem that some studies did find IOR after highly salient color singleton cues (Theeuwes & Chen, 2005; Theeuwes & Godijn, 2002), while others failed to find the effect (Gibson & Amelio, 2000; Pratt & McAuliffe, 2002).

Differences in manual and saccadic responses. Briand, Larrison, and Sereno (2000) found different timecourses for IOR in manual and saccadic response modalities, with IOR being observed after shorter CTOAs (~130-200 ms) in saccadic response mode. Additionally Pratt and Neggers (2008) reported stronger IOR in tasks carried out using saccadic compared to manual response modes. These differences are likely caused by differential cortical and subcortical contributions to IOR. Based on these findings Godijn and Theeuwes (2004, p. 545) suggested that the failure to find IOR in some studies, which poses a problem for using IOR as a hallmark of exogenous capture, may have been the result of the procedures (in this case response modes) used, which may have been too insensitive for the detection of IOR. In the study of Gibson and Amelio, for example, only keypress responses were used although as documented by the studies of Briand et al. and Pratt and Neggers saccadic responses may be better suited for detecting IOR. This hypothesis is the key point addressed by the study carried out for this thesis.

Objectives of the Present Study

A short summary of the theoretical foundation. Before stating the research questions it may be helpful to summarize the contents of the introduction in a more compact form. First the reader learned how humans can orient their selective visual attention in space not only by movements of the eyes but also by tuning their perceptual systems (covert attentional orienting). Next the important role of saliency in spatial visual attention was discussed as well as how involuntary saliency based covert orienting can be used to address questions on the nature of attentional modulation of early visual processing by using physiological measurements for the computation of performance and attentional capture indicators (e.g. validity effects like attentional capture and IOR). Furthermore two competing theories responsible for a long lasting debate in cognitive psychology about the early stages of visual orienting have been presented, namely the pure capture (or bottom-up) account whose supporters reject a role of attention in early visual processing and the contingent capture (or top-down) account whose supporters suggest that attention can be used to optimize early visual processing by tuning the perceptual system to task relevant features. Since deciding which of the competing theories is correct has proven difficult by only measuring attentional capture by salient stimuli, the phenomenon of IOR was introduced to the debate as a hallmark of stimulus driven capture. However evidence that IOR is indeed a hallmark of stimulus driven capture is mixed, especially when features like color, which are cortically processed before influencing orienting, are used. Some studies did find IOR after salient color stimuli while others did not (see references on the previous page). This has led proponents of the pure capture account to suggest that differences in the experimental procedures used to study IOR may have been responsible for the inconsistent results. Therefore this study aims at answering the question whether the proposed differences in experimental procedures (especially different response modes but also types of tasks) are indeed responsible for the divergence in the obtained results and hereby hopes to contribute to a better understanding of whether there is a role for attention in early visual processing.

Rationale of the carried out experiments. To tackle this question we build on the study of Gibson and Amelio and initially tried to replicate their results in an experiment based on a variation of the spatial cueing paradigm utilizing a manual (keypress) response mode and a discrimination task. We used cues appearing in the periphery of the participants visual field (guaranteed by an eye tracker) since peripheral cues consistently resulted in strong IOR in many studies (see e.g. Chica et al., 2014). The use of color singleton cues is a standard procedure in the field to operationalize high saliency conditions required for attentional capture. In a second experiment we then extended Gibson and Amelio’s approach towards more sensitivity for the detection of IOR by adding an experiment based on the exact same procedure and stimuli, but this time utilizing a saccadic response mode and a task which requires the participants to only detect the target stimulus (by a saccade to it’s location) instead of discriminating it (a limitation of Gibson and Amelio’s study pointed out by the authors themselves; 2000, p. 503). As an addition we used the statistical method of vincentization (or binning; see e.g. Burnham, 2013; Rouder & Speckman, 2004) in the analysis of our results to check for validity effects in early and late responses which may be obscured by the usually used mean centered statistical procedures. Because this experiment was part of a larger series of experiments we also used two different cue colors per participant (matching the target color or not) to check for contingent capture. The details of the used experimental design, the procedure and participants of our study will be described in the next chapter. Explicitly stated our research questions were as follows:

- (1) Can the results of Gibson and Amelio (2000) who did not find IOR after peripheral color singleton cues be replicated with our slightly differing design?
- (2) Is the manual response modality or the used discrimination task the reason for the absence of IOR in Gibson and Amelio’s study?
- (3) Can the analysis of RT distributions which allows for examining early and late responses in this case reveal IOR which is obscured by the mean focused statistical procedure commonly used in experiments on visual attention?

Methods

Procedure and Design

To answer the stated questions two experiments based on a variant of Posner's classic spatial cueing paradigm were carried out, differing only in response modalities (manual or saccadic) and the nature of the task (discrimination or detection). Stimulus material (consisting of **E**'s, **3**'s and placeholder **■**'s) and procedure were exactly the same in both experiments and have in similar forms been used for example by Deubel and Schneider (1996). We used peripheral non-predictive color singleton cues and color singleton targets to trigger involuntary orienting. Before both experiments participants were informed that only the stimulus in the target color shown at the end of each trial is relevant to their response and that it could only appear on specific positions. Other events before the presentation of the target and the distractor color were mentioned in the introductory text as just "appearing" during some trials. Participants were further informed that they had to keep their eyes on the fixation cross at all times during each trial (except when responding in the saccadic condition) and that their responses should be made as quickly and as accurate as possible. To ensure that the instructions were followed and that our manipulations would affect covert orienting of attention an eye-tracker monitored whether fixation was kept (divergence within trials by more than $\sim 3.5^\circ$ degrees was counted as an error). The trials consisted of the sequential presentation of a 500 ms fixation display, a 50 ms cue display, a variable length (50, 150, 950 ms) fixation display (realizing CTOA's of 100, 200, and 1000 ms), and a target display which was shown until a response had been made (or time since onset exceeded 999 ms; for an illustration see figure 4 on the following page).

A trial was started at will by pressing the space key on a standard keyboard which was placed in front of the participant. To keep exhaustion low, trials were presented in 10 blocks of at least 60 trials each (incorrectly answered trials were repeated at a random point in the current block), with short resting periods in between. During each block ($2 \times 2 \times 3 =$) 12 different conditions were presented in random order resulting in overall 50 measurements per

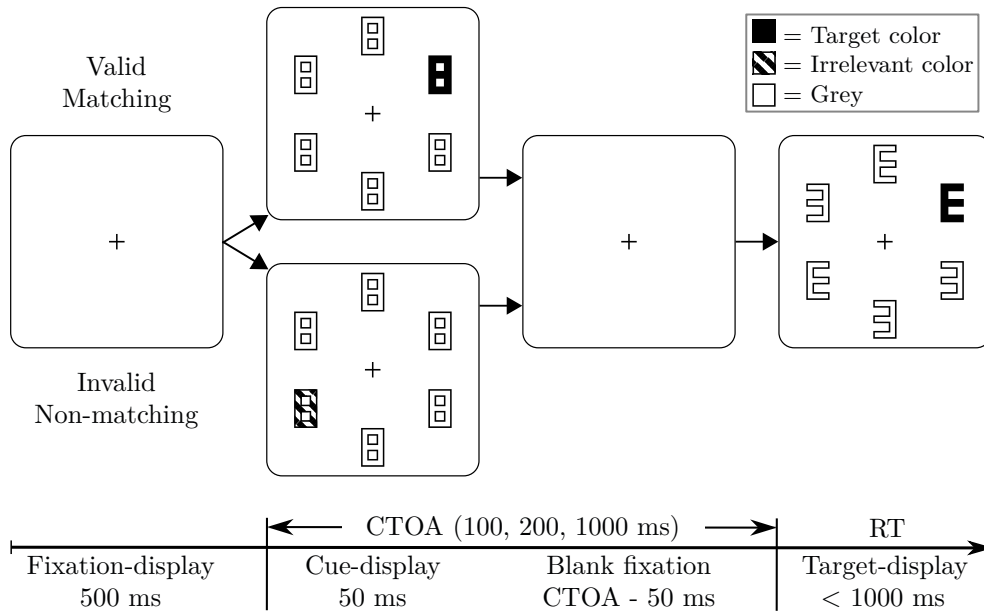


Figure 4. Symbolic depiction of procedure in individual trials. The upper cue display represents a valid (same location), matching (same color as target) cue, the lower cue display represents an invalid (different position) and non-matching (different color than target) cue. The arrow underneath illustrates the temporal sequence of events. Cue- and target stimuli could only appear on the two left and two right positions. Cue and target could appear in two out of three colors (red, green, and blue). The target color was the same in all trials of a participant. For readability stimuli are drawn in twice their original size.

participant and condition (600 measurements per participant). The experimental conditions were defined as follows: (a) Target and cue could appear subsequently in the same position (valid cue) or in different positions (invalid cue) allowing for the computation of validity effects (attentional capture and IOR). The position of cues and targets was randomly varied between the four left and right positions. Overall (and within each block) cues were valid in half of all trials and invalid in the other half, thereby rendering the cues position non-predictive of the target position and irrelevant to the required response (note however that since the possible number of locations was four, cues are slightly predictive of the targets location). (b) The relation of cue and target color was matching in half and non-matching in the other half of trials, thereby allowing to examine the influence of task relevant and task irrelevant cue colors on validity effects. (c) The CTOA was varied in three stages (100, 200 and 1000 ms) to examine the timecourse of attentional orienting.

Each participant was tested independently after being randomly assigned to one of the two response conditions which were additionally split into six cue-target color relation groups covering all possible combination pairs of red, green and blue, to account for differential influences of the individual colors. Testing was carried out in a quiet, dimly illuminated room in an eye tracking laboratory of the University of Vienna. Including informed consent and pretests for normal color vision the experimental sessions took on average a little more than one hour. The time interval for resting between experimental blocks was used by the participants according to their demand, hence it's length was varying from less than a minute to a couple of minutes.

The manual response experiment. In the manual response experiment the participant's task was to react as quickly as possible to the appearance of the target stimulus by pressing one of two keys depending on the target's shape (**E** or **3**). This design mimics Gibson and Amelio (2000) color condition (however extending it with non-matching color cues and a 200 ms CTOA) and was implemented to check whether we would be able to replicate their results with our slightly differing design. That is, we expected to find contingent capture (faster RTs in valid versus invalid trials after non-predictive cues in target matching color) in short CTOA conditions, but no IOR with this design (see table 1 on the next page). A result in line with the contingent capture account should elicit attentional effects only after matching and not after non-matching color cues (e.g. Folk & Remington, 1998).

The saccadic response experiment. In the saccadic response experiment no discrimination was necessary, the shape of the target stimulus was completely irrelevant. The task was instead to locate the target and saccade to it (fixate it with the eyes). If the results of Gibson and Amelio (2000) have been caused by an insensitivity of the task and/or the manual response mode (Pratt & Neggers, 2008) for the detection of IOR, this experiment should unveil hidden IOR by changing to a more IOR sensitive detection task and the eventually more IOR sensitive saccadic response mode. Following this assumption and the contingent capture account we expected to see capture effects and earlier starting IOR after matching color singleton cues (see table 1 on the following page).

Table 1
Expected Experimental Results

	CTOA		
	100	200	1000
Manual response			
Matching color	↑	↑	–
Non-matching color	–	–	–
Saccadic response			
Matching color	↑	↓	↓
Non-matching color	–	–	–

Note. ↑-arrows represent attentional capture.

↓-arrows represent inhibition of return.

Apparatus and Stimuli

Stimuli were presented on a 19" CRT-monitor (Sony Multiscan G400) with a framerate of 100 Hz and a resolution of 1024 x 768 pixels (72 dpi). For a constant distance and viewing angle during stimulus presentation participants sat in front of the monitor resting their head on a chin rest at a distance of 57 cm. The setup generating stimuli and taking measurements consisted of a standard PC (AMD Athlon 5000B, 2GB RAM, Nvidia GeForce GT 220, Microsoft Windows XP Professional 32bit - Service Pack 3) running MATLAB (R2009a - Version 7.8.0.347), which was connected to an SR Research 'Eyelink 1000' Desktop Mount system (software version 4.52, 35 mm lens) sampling eye positions monocular at a frequency of 1000 Hz. The MATLAB program used was written by Dr. Heinz Werner Priess and was a slightly modified version of a program used in previous eye tracking studies conducted at our lab (see Ansorge, Priess, & Kerzel, 2013). In the manual condition participants responded by pressing the *F*- and *J*-keys on a German layout standard keyboard.

All stimuli used were isoluminant (30 cd/m²) and presented on a dark background (0.2 cd/m²), the color singletons were therefore mainly activating parvocellular pathways. The fixation cross presented before and during trials was a plus sign in the middle of the display (with a size of 1.0° x 1.0°). It was presented in white before each trial and became greyed out (CIELab coordinates: 6.9, 16.8) during presentation of cue and target displays

as well as during the variable length blank fixation interval between them. The cue display consisted of the fixation cross presented in the middle of the screen as well as one colored **H** and five grey placeholder **H**'s presented equidistant with regard to the fixation cross at positions 2, 4, 6, 8, 10 and 12 of an analog clock at an eccentricity of 7° and a size of $1.7^\circ \times 1.0^\circ$. The cue appeared randomly either on positions 2, 4, 8 or 10 and was colored in one of two colors (either matching or non-matching) out of red (CIE Lab: 47.6, 41.1), green (CIE Lab: -30.2, 24.9) or blue (CIE Lab: 46.9, -89.0) depending on the experimental condition the participant was assigned to. The target display matched the configuration of the cue display except that all the stimuli previously presented in the shape of an **H** were now presented as half **E**'s and half **3**'s and the colored stimulus previously acting as a (one out of two) color cue appeared only in the target color (red, green or blue) the participant had been assigned to. The cue display was presented for 50 ms while the target display was displayed until the participant responded or a duration of 999 ms was exceeded.

Eye tracking was monocular. The start of a saccade was defined by an eye movement faster than $80^\circ/s$. Once the eye movement speed dropped below this value again, it was determined whether it landed in an area $\sim 1.5^\circ$ around the center of the possible stimulus locations. The landing location of saccades was saved. The time between onset of the target stimulus and saccade landing was saved as the RT. Responses faster than 100 ms were discarded because they are too fast to represent genuine reactions. Responses slower than 999 ms were not recorded because the probability is high that these reactions were caused by distractions and do not represent the kind of focused attention we wanted to examine.

Participants

Twenty-four participants (aged 18 – 32; 12 female) were recruited using our labs internal recruitment system RSAP (Rekrutierungssystem Allgemeine Psychologie) and participated for course credit. Each experiment had six female and six male participants with a mean age of 23 years. Before the experiment all participants provided informed consent and reported normal or corrected to normal visual acuity and normal color vision.

Results

Data Preparation

By using the data collection strategy of saving only those trials with reactions below 1000 ms only a small amount of trials which RTs below 100 ms had to be removed. Trials in which errors occurred, be it a loss of tracking out of technical reasons or a “wrong” response in terms of the instruction, were repeated at a random point of the current block. Due to a bug in the experimental software the overall first trial of a participant was not saved nor repeated when an error was done, therefore the planned 600 “correct” (in terms of the instruction) RT measurements were not reached in some of the participants. The described error happened five times in the manual response experiment and six times in the saccadic response experiment, resulting in only 599 data points in 11 of 24 participants. Since our analysis was carried out on means consisting of at least 10 individual measures (for binning) and the distribution of missing data is assumed to be random across experimental conditions, the loss of these data was not considered relevant for the final result.

Notes on reaction time distributions. Binning was done by ordering all 50 RTs of each participant and condition from fastest to slowest and then computing five means of 10 subsequent RTs each. After this procedure the variable bin was ready to be added to the statistical tests of differences between condition means.

Notes on error rates. The computation of ERs was done by counting errors per person and condition and dividing the number of errors by the overall number of trials absolved under the conditions of interest. Because by nature of the used tasks error numbers are relatively low and of only limited variance, all ERs were arcus-sinus transformed to account for this fact before carrying out statistical analysis.

Notes on statistics. All statistical analysis were carried out with an alpha level of .05. Whenever Mauchly’s Test of Sphericity indicated a violation of the sphericity assumption, ANOVA results were adjusted by correcting the degrees of freedom using Greenhouse-Geisser’s ϵ -estimates.

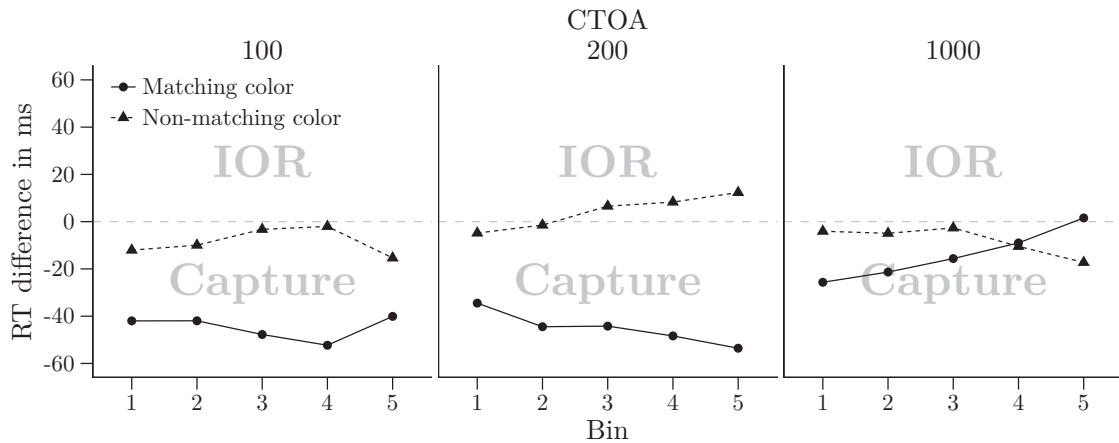


Figure 5. Validity effect (RT valid - RT invalid) tendencies in early and late manual responses. Although the interaction of validity, cue color, CTOA, and bin was rendered non-significant by the applied Greenhouse-Geisser correction ($p = .088$) the plot provides an overview of validity effect tendencies in early and late responses. Notice the much stronger capture by matching color cues in 100 ms and 200 ms CTOA conditions, as well as the IOR tendency of late responses after non-matching color cues in 200 ms conditions. In 1000 ms conditions validity effect tendencies are much smaller and only in it's latest responses a classic IOR pattern can be found.

Results of the Manual Response Experiment

Analysis of reaction times. Mean RTs of trials in which the correct answer was given were submitted to a three way repeated-measures ANOVA (RM-ANOVA) with the variables validity (valid, invalid), cue color (matching, non-matching), CTOA (100, 200, 1000 ms) and bin (1st, 2nd, 3rd, 4th, 5th). The ANOVA revealed a significant main effect of validity, $F(1,11) = 29.06$, $p < .001$, with faster responses in valid versus invalid conditions (558 ms vs. 577 ms). Further it revealed two-way interactions of validity and cue color, $F(1,11) = 17.1$, $p = .002$, validity and CTOA, $F(2,22) = 3.51$, $p = .059$, a three-way interaction of validity, cue color and CTOA, $F(2,22) = 8.72$, $p = .005$, as well as a four-way interaction of validity, cue color, CTOA and bin, which however lost significance after the p -correction procedure, $F(8,88) = 2.47$, $p = .088$ (before correction $p = .018$; for an overview of the validity effect tendencies see figure 5). To understand the direction of significant differences revealed by the ANOVA we conducted post hoc paired t tests next.

Table 2

Results of Paired t-Tests: Mean RT in Milliseconds, Manual Response

	Validity		Difference	<i>t</i>	<i>df</i>	<i>p</i>
	Valid	Invalid				
CTOA = 100 ms						
Matching color	544.02 (40.48)	589.16 (51.98)	-45.14	-4.87	11	***
Non-matching color	561.97 (46.68)	570.64 (44)	-8.67	-1.09	11	.298
CTOA = 200 ms						
Matching color	539.29 (36.18)	584.30 (46.42)	-45.01	-6.28	11	***
Non-matching color	573.66 (47.28)	569.47 (43.52)	4.19	1.23	11	.245
CTOA = 1000 ms						
Matching color	559.99 (45.22)	574.00 (49.45)	-14.01	-1.91	11	.082
Non-matching color	567.17 (45.74)	575.34 (46.69)	-8.17	-1.68	11	.121

Note. Standard deviations appear in parentheses below means.CTOA = Cue target onset asynchrony. *** $p < .001$.

The two-way interaction of validity and cue color reflects significantly lower RTs with valid versus invalid cues only in matching color (548 ms vs. 582 ms, $t(11) = -5.55$, $p < .001$) but not in non-matching color conditions (568 ms vs. 572 ms, $t(11) = -1.03$, $p = .326$). The interaction of validity and CTOA is due to faster RTs in valid versus invalid conditions in the shorter (100 ms: 552 ms vs. 580 ms, $t(11) = -4.03$, $p = .002$; 200 ms: 556 ms vs. 577 ms, $t(11) = -6.16$, $p < .001$) compared to the longer CTOA condition (1000 ms: 563 ms vs. 575 ms, $t(11) = -2.7$, $p = .02$). The three way interaction of validity, cue color and CTOA is a result of significantly faster RTs in valid versus invalid trials only in matching cue color conditions of the first two CTOAs (100 ms: 544 ms vs. 589 ms, $t(11) = -4.87$, $p < .001$; 200 ms: 539 ms vs. 584 ms, $t(11) = -6.28$, $p < .001$; 1000 ms: 560 ms vs. 574 ms, $t(11) = -1.91$, $p = .082$) and not in non-matching cue color conditions (all p values $\geq .121$, for an overview see table 2).

Table 3
Error Rates (Wrong Button Pressed)

	CTOA			total
	100	200	1000	
Valid	.0376 (48)	.0621 (83)	.0948 (130)	.0663 (261)
Matching color	.0423 (27)	.0571 (38)	.0894 (63)	.0647 (128)
Non-matching color	.0321 (21)	.0667 (45)	.0977 (67)	.067 (133)
Invalid	.0528 (70)	.0582 (76)	.1062 (148)	.0735 (294)
Matching color	.0465 (31)	.0487 (32)	.1116 (79)	.0713 (142)
Non-matching color	.0569 (39)	.0658 (44)	.0995 (69)	.0752 (152)
Matching color	.0451 (58)	.0533 (70)	.1028 (142)	.0683 (270)
Non-matching color	.0459 (60)	.0668 (89)	.0989 (136)	.0714 (285)
Total	.0459 (118)	.0603 (159)	.1010 (278)	.07 (555)

Note. Absolute number of errors in parentheses.

Analysis of error rates. In the manual response experiment 1.08 % of trials were too fast responses (< 100 ms after target appearance; 0.04 %) and tracking errors / failures to keep fixation (1.04 %). The ERs of the remaining 7 % of trials in which a wrong response was given ($= 555$; see table 3) were submitted to a RM-ANOVA with the variables validity (valid, invalid), cue color (matching, non-matching) and CTOA (100, 200, 1000 ms).

The ANOVA revealed a main effect of CTOA, $F(1,11) = 21.96$, $p < .001$, with smaller ERs in the 1000 ms condition (1.01 %) in comparison to the 100 ms (4.59 %, $t(11) = -6.35$, $p < .001$) and 200 ms conditions (6.03 %, $t(11) = -4.1$, $p = .002$). The difference in error rates between 100 ms and 200 ms conditions did not reach significance ($t(11) = -2.19$, $p = .051$). No other significant effects were found.

Results of the Saccadic Response Experiment

Analysis of reaction times. Again the mean RTs of correct trials were submitted to a repeated-measures ANOVA with the variables validity (valid, invalid), cue color (matching, non-matching), CTOA (100, 200, 1000 ms) and bin (1st, 2nd, 3rd, 4th, 5th). The ANOVA revealed a main effect of CTOA, $F(1,11) = 35.9$, $p < .001$, reflecting significantly slower RTs in the first two CTOA levels (100 ms: 324 ms, 200 ms: 327 ms) compared to the third (1000 ms: 279 ms). The ANOVA revealed further two-way interactions of validity and cue color, $F(1,11) = 9.76$, $p = .01$, validity and CTOA, $F(2,22) = 7.92$, $p = .004$, validity and bin, $F(4,44) = 5.46$, $p = .01$, and CTOA and bin, $F(1,11) = 13.15$, $p < .001$. Lastly a three-way interaction of validity, cue color and bin was found which failed to reach significance after correcting for violations of the sphericity assumption, $F(4,44) = 3.98$, $p = .072$.

The two-way interaction of validity and cue color is a result of faster RTs after valid versus invalid cues only in matching color (302 ms vs. 315 ms; $t(11) = -2.48$, $p = .031$) but not non-matching color conditions (312 ms vs. 310 ms; $t(11) = 0.55$, $p = .59$). The two-way interaction of validity and CTOA results from significantly faster RTs in valid versus invalid conditions only in the shortest CTOA condition (100 ms: 314 ms vs. 332 ms; $t(11) = -3.52$, $p = .005$) and not in the two longer ones (200 ms: 326 ms vs. 328 ms, $t(11) = -0.37$, $p = .718$; 1000 ms: 279 ms vs. 279 ms, $t(11) = -0.1$, $p = .921$). The interaction of validity and bin became significant because significantly faster RTs in valid versus invalid conditions were only prevalent in the fastest of RTs (1st bin: 222 ms vs. 238 ms, $t(11) = -2.31$, $p = .041$; bin's 2-5: all p 's $\geq .192$, for details see table 4 on the next page). The two-way interaction of CTOA and bin is presumably a result of the tendency of significant differences between the first two CTOA levels (100 ms, 200 ms) and the last one (1000 ms) to become bigger with later responses (for details see table 5 on page 35).

Table 4

Results of Paired t Tests: Mean RT in Milliseconds, Saccadic Response

	Validity		Difference	t	df	p
	Valid	Invalid				
Matching color	301.61 (47.94)	315.11 (53.83)	-13.5	-2.48	11	.031*
Non-matching color	312.57 (51.99)	310.91 (58.14)	1.66	0.55	11	.59
CTOA = 100 ms	313.95 (57.1)	332.37 (60.46)	-18.42	-3.52	11	.005*
CTOA = 200 ms	326.26 (46.79)	328.1 (58.18)	-1.84	-0.37	11	.718
CTOA = 1000 ms	278.91 (46.59)	278.55 (54.35)	0.36	0.1	11	.921
1st bin	221.61 (36.85)	238.26 (42.22)	-16.65	-3.9	11	.002*
2nd bin	264.13 (46.05)	270.13 (53.33)	-6	-1.39	11	.192
3rd bin	294.16 (51.57)	297.88 (58.21)	-3.72	-0.91	11	.383
4th bin	331.46 (57.21)	335.47 (62.64)	-4.01	-0.99	11	.345
5th bin	423.55 (65.48)	423.3 (68.58)	0.25	0.05	11	.961

Note. Standard deviations in parentheses below means. CTOA = Cue target onset asynchrony. * = $p < .05$, *** = $p < .001$.

Table 5

Results of Paired t Tests: Mean RT in ms, Saccadic Response

	CTOA			difference	<i>t</i>	<i>df</i>	<i>p</i>
	100	200	1000				
bin 1	235.79 (43.29)	238.29 (41.88)	-	-2.5	-0.53	11	.604
	235.79 (43.29)	-	215.73 (36.17)	20.06	3.17	11	.009*
	-	238.29 (41.88)	215.73 (36.17)	22.56	3.8	11	.002*
bin 2	277.11 (52.72)	280.47 (51.31)	-	-3.36	-0.76	11	.461
	277.11 (52.72)	-	243.82 (47.78)	33.29	4.91	11	***
	-	280.47 (51.31)	243.82 (47.78)	36.65	5.90	11	***
bin 3	306.91 (60.29)	313.61 (54.36)	-	-13.4	-1.55	11	.149
	306.91 (60.29)	-	267.54 (52.81)	39.37	5.24	11	***
	-	313.61 (54.36)	267.54 (52.81)	46.07	6.72	11	***
bin 4	348.36 (68.4)	355.09 (57.52)	-	-6.73	-1.2	11	.256
	348.36 (68.4)	-	296.94 (52.81)	51.42	5.36	11	***
	-	355.09 (57.52)	296.94 (52.81)	58.15	6.72	11	***
bin 5	451.55 (77.4)	449.11 (69.01)	-	2.44	-0.39	11	.706
	451.55 (77.4)	-	369.62 (64.3)	81.39	5.98	11	***
	-	449.11 (69.01)	369.62 (64.3)	79.49	5.87	11	***

Note. Standard deviations in parentheses below means.

* = $p < .05$, *** = $p < .001$.

Analysis of error rates. In the saccadic response experiment 3.45 % of trials (= 272) were too fast responses (< 100 ms after appearance of the target; 0.23 %) or tracking errors / failures to keep fixation (3.22 %). ERs of the remaining 4.08 % erroneous trials in which a wrong response, either to the cued location or a different location, was given (= 325), were as before arcus-sinus transformed and submitted to a repeated-measures ANOVA with the variables validity (valid, invalid), cue color (matching, non-matching) and CTOA (100, 200, 1000 ms). The ANOVA revealed a significant main effect of cue color, $F(1,11) = 5.41$, $p = .04$, with more errors in matching than non-matching cue color trials (4.69 % vs. 3.43 %), a significant two way interaction of validity and CTOA, $F(2,22) = 6.42$, $p = .006$, and a significant three way interaction of validity, cue color and CTOA, $F(2,22) = 4.13$, $p = .03$ (for an overview of ERs see table 6).

The two-way interaction of validity and CTOA represented fewer errors under valid versus invalid cue conditions only in the 100 ms (2.27 % vs. 6.31 %, $t(11) = -2.31$, $p = .041$) and 200 ms (2.94 % vs. 4.82 %, $t(11) = -2.88$, $p = .015$), but not in the 1000 ms (4.18 % vs. 3.28 %, $t(11) = 1.66$, $p = .124$) CTOA conditions. The three-way interaction reflected that the picture found in the two-way interaction was clearly a result of fewer errors under valid versus invalid cue conditions in matching color trials (100 ms: 1.85 % vs. 7.24 %, $t(11) = -2.53$, $p = .028$; 200 ms: 2.72 % vs. 6.96 %, $t(11) = -4.15$, $p = .002$; 1000 ms: 4.66 % vs. 3.59 %, $t(11) = 1.1$, $p = .297$), but not in non-matching color trials (100 ms: 2.62 % vs. 5.1 %, $t(11) = -1.26$, $p = .235$; 200 ms: 3.06 % vs. 2.45 %, $t(11) = 0.66$, $p = .526$; 1000 ms: 3.64 % vs. 2.9 %, $t(11) = 1.01$, $p = .334$).

Table 6

Error Rates (Saccades to Wrong Locations)

	CTOA			total
	100	200	1000	
Valid	.0227 (30)	.0294 (39)	.0418 (58)	.0318 (127)
Matching color	.0185 (12)	.0272 (18)	.0466 (33)	.0314 (63)
Non-matching color	.0262 (18)	.0306 (21)	.0364 (25)	.0315 (64)
Invalid	.0631 (89)	.0482 (65)	.0328 (44)	.0492 (198)
Matching color	.0724 (52)	.0696 (49)	.0359 (25)	.0611 (126)
Non-matching color	.051 (37)	.0245 (16)	.029 (19)	.0364 (72)
Matching color	.0473 (64)	.0495 (67)	.0418 (58)	.0469 (189)
Non-matching color	.0401 (55)	.0279 (37)	.0329 (44)	.0343 (136)
Total	.0442 (119)	.0391 (104)	.0375 (102)	.0408 (325)

Note. Absolute number of errors in parentheses.

To further investigate whether there are differences in the ability of matching and non-matching color cues to misguide saccades to cued locations we performed another ANOVA, this time using the ERs of invalid trials only, with the variables direction of saccade (to cued location, to different location), cue color (matching, non-matching) and CTOA (100, 200, 1000 ms). This ANOVA revealed a main effect of cue color, $F(1,11) = 7.99$, $p = .016$, reflecting more misguidance of saccades to invalidly cued locations after matching versus non-matching cues (6.11 % vs. 3.64 %), a two way interaction of direction and CTOA, $F(2,22) = 6.11$, $p = .009$, and a three way interaction of direction, cue color and CTOA, $F(2,22) = 3.53$, $p = .044$.

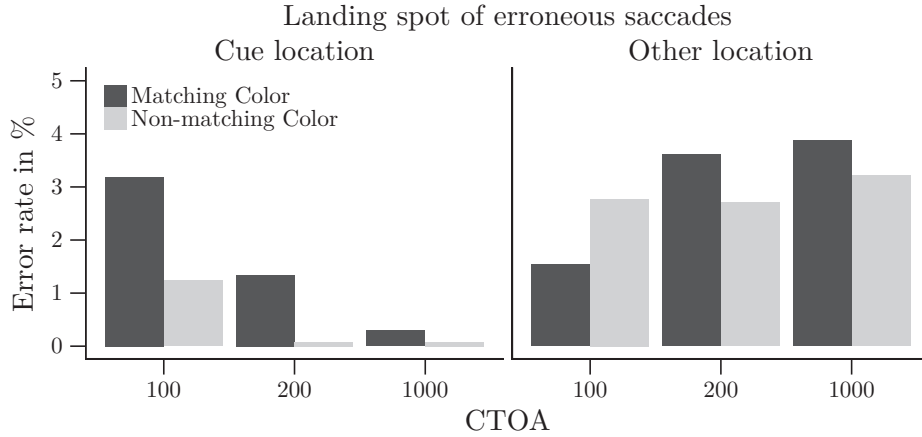


Figure 6. Illustration of erroneous saccades to cued and other locations after matching and non-matching color cues. Note the higher number of erroneous saccades to the cued location after matching color cues especially in the two short, but not in the long CTOA condition. Generally in the longer CTOAs erroneous saccades to the cued location are rare.

The two way interaction of direction and CTOA was a result of less erroneous saccades to cued versus uncued locations in the two longer CTOA conditions (200 ms: 3.48 % vs. 1.22 %, $t(11) = 3.99$, $p = .001$; 1000 ms: 1.8 % vs. 1.45 %, $t(11) = 0.83$, $p = .213$), but not in the shortest CTOA condition (100 ms: 4.17 % vs. 1.99 %, $t(11) = 1.58$, $p = .071$).

The three way interaction of direction, CTOA and cue color reflected no significant differences in the number of saccades directed at the cues location versus another location after both matching and non-matching color cues in the 100 ms CTOA condition (matching: 3.19 % vs. 1.54 %, $t(11) = -1.31$, $p = .218$; non-matching: 1.24 % vs. 2.77 %, $t(11) = -1.5$, $p = .163$), but differences in the number of saccades directed at the cues location versus another location between matching and non-matching color cues in the 200 ms condition (matching: 1.34 % vs. 3.61 %, $t(11) = -2.2$, $p = .05$; non-matching: 0.01 % vs. 2.71 %, $t(11) = -2.51$, $p = .029$) and less saccades directed at the cues location versus another location after both matching and non-matching color cues in the 1000 ms CTOA condition (matching: 0.3 % vs. 3.88 %, $t(11) = -2.41$, $p = .035$; non-matching: 0.01 % vs. 3.22 %, $t(11) = -2.39$, $p = .036$). For an illustration of the error pattern in invalid trials separated by landing locations of erroneous saccades see figure 6.

Discussion

General Discussion

The experiment conducted for this thesis examined the question whether too insensitive measures were responsible for mixed findings regarding the occurrence of IOR after color singleton cues in spatial cueing paradigms. The importance of this question arises from the interpretation of IOR as a hallmark of attentional capture in context of the debate about a purely bottom-up versus top-down influenced nature of early visual processing. If IOR can indeed be interpreted as a hallmark of attentional capture one has to explain why some studies did find IOR after attention capturing highly salient color singleton cues, while others did not. Some authors suggested that those studies that did not find IOR after color singleton cues may have used too insensitive measures to detect the effect (Godijn & Theeuwes, 2004). In the current study therefore the conditions for a detection of IOR were optimized by using a probably more sensitive response mode (saccadic instead of manual) and task (detection instead of discrimination), as well as a statistical procedure which allows for statistical search for IOR not only in the overall mean RTs of conditions but also in the means of early and late responses in each condition. To examine whether our design was suited to tackle this question we also carried out an initial experiment which tried to replicate the results of one study in which a manual response mode and a discrimination task were used and no IOR after color singletons could be found (Gibson & Amelio, 2000). Since a replication of these results with our differing design can be seen as a precursor to the other two questions I will discuss the results with regard to this question first.

- (1) Can the results of Gibson and Amelio (2000) who did not find IOR after peripheral color singleton cues be replicated with our slightly differing design?

The most important results to answer this question are summarized in table 2 on page 31, which presents the outcome of post hoc analysis applied to RTs collected in the manual response experiment. A look at this table shows that we observed attentional capture

(lower RTs in valid vs. invalid conditions) under circumstances in which cue and target color were the same and the temporal difference between cue and target was comparatively small (CTOA: 100 and 200 ms). This result is complemented by the results in the analysis of ERs (less errors in 100 ms conditions; see page 32). We did however not find attentional capture in conditions where cue and target were presented in different colors and most importantly we did not find any attentional effects in conditions with a long duration between cue and target (CTOA: 1000 ms). These results are completely in line with those found by Gibson and Amelio, who observed contingent capture after color singleton cues in short CTOA conditions, but no IOR even with a long CTOA of 1000 ms. That is, despite different stimulus material and slightly altered procedure (e.g. the additional CTOA level of 200 ms) we were able to replicate Gibson and Amelio's result and it should therefore be reasonable to use this design to tackle our main hypothesis.

The use of bins in our analysis introduced to look for attentional effects in early and late responses which may otherwise be missed, revealed no significant effects after a correction for violations of the sphericity assumption. The tendencies of RTs in early and late responses, as illustrated in figure 5 on page 30, are nevertheless interesting, because of the development of validity tendencies after cues colored differently than the target in the 200 ms conditions. While in the earliest responses (bins 1 and 2) there are still capture tendencies, bins 3, 4, and 5 show IOR tendencies which however disappear in 1000 ms conditions. Typically IOR can be observed after CTOAs of approximately 200 ms, therefore the build up of IOR in those late responses could be interpreted as being in line with Theeuwes disengagement hypothesis. Remember, Theeuwes suggests that contingent capture effects are the result of faster disengagement after non-matching cues. Assuming that this hypothesis is correct one might also see a faster build up of IOR after non-matching cues. However such an explanation needs to be handled with great caution since the results on which it grounds have not been significant and it faces the problem of the disappearance of IOR in 1000 ms conditions. In the next section we will come back to these questions and discuss possible explanations for the absence of IOR in this experiment.

Table 7
Expected and Obtained Experimental Results

	CTOA			CTOA		
	100	200	1000	100	200	1000
Manual response						
Matching color	↑	↑	–	↑	↑	–
Non-matching color	–	–	–	–	–	–
Saccadic response						
Matching color	↑	↓	↓	↑	–	–
Non-matching color	–	–	–	–	–	–
	Expected			Obtained		

Note. ↑-arrows represent capture. ↓-arrows represent IOR.

- (2) Is the manual response modality or the used discrimination task the reason for the absence of IOR in Gibson and Amelio’s study?

Since we were able to replicate the findings of Gibson and Amelio with our design, we now changed the response mode from manual to a presumably more IOR sensitive saccadic and the task from discrimination to detection (saccading to the location of the target) while preserving stimulus material and procedure. Table 4 on page 34, summarizes the most important results in RTs measured in this experiment. Although contingent capture is not as clearly indicated here as it is in the manual response experiment, since a three-way interaction of validity, cue color, and CTOA is missing, the tendency found in the two-way interactions of validity and cue color, validity and CTOA, and validity and bin is the same as in the manual response experiment with significantly lower RTs only after matching but not non-matching color singleton cues in valid versus invalid trials ($302\text{ ms} < 315\text{ ms}$) and significantly shorter RTs after valid versus invalid cues only in the shortest CTOA condition ($314\text{ ms} < 332\text{ ms}$) and in the earliest of responses (bin 1: $222\text{ ms} < 238\text{ ms}$). This pattern of results can safely be interpreted as an indication of contingent capture, although in line with the overall much lower RTs in this experiment the effect seems, as expected, to diminish much faster and is therefore only present in 100 ms conditions. Again there is no indication of IOR, neither in the 200 ms, nor in the 1000 ms CTOA conditions (see table 7).

Like in the manual response experiment the picture found in the ERs complements the results of attentional capture in the shortest CTOA observed in the analysis of RTs. In ERs even the three-way interaction of validity, cue color and CTOA can be found, that failed to reach significance in the analysis of RTs (it is caused by fewer errors after valid vs. invalid cues in the 200 ms CTOA of matching but not non-matching conditions; see page 36). Prominent in the overview of saccades to wrong locations presented in table 6 on page 37, is the high number of errors in the short CTOAs of invalidly cued trials. The results of further analysis (see figure 6 on page 38) reveal that the higher number of errors is a result of the highly attention attracting properties of matching color cues which give rise to erroneous saccades to cued locations in invalidly cued and short CTOA conditions.

To conclude it can be stated that contrary to our main hypothesis, which was formulated based on Godijn and Theeuwes suspicion that the less sensitive manual response mode used by Gibson and Amelio might be responsible for the lack of IOR in their experiment (2004; p. 545), can not be corroborated by the obtained results. Nevertheless there may be other explanations for the lack of IOR as will be discussed in the next section.

- (3) Can the analysis of RT distributions which allows for examining early and late responses in this case reveal IOR which is obscured by the mean focused statistical procedure commonly used in experiments on visual attention?

The third formulated hypothesis was already partly answered by the discussion of the previous two hypothesis. Since we did not find any IOR even when considering differences between early and late responses and no important significant interactions with other variables were found, the answer to the question raised in this hypothesis is in the case of the conducted experiment: No. Nonetheless the binning procedure revealed interesting tendencies in late CTOA 200 ms conditions of the manual response experiment and as we will see now the possibility remains that because of specific characteristics of our experiment there was nothing to be found and binning might be worthwhile for detecting IOR or capture in other experiments.

Limitations of the Current Experiment

Given the results of the carried out experiments the question remains what may be responsible for the observed lack of IOR after color singleton cues in both manual/discrimination and saccadic/detection tasks. In this section three different but probably intertwined explanations grounded on a larger literature base will be provided, of which one is characterizing IOR as bottom-up or stimulus driven, while the other two are more in line with top-down views on attentional orienting.

The first, bottom-up compatible, explanation is grounded on the conception that at least parts of IOR are oculomotor effects brought about by direct inputs to the superior colliculus (e.g. Klein & Hilchey, 2011). Klein and colleagues recently found that oculomotor components of IOR, which are especially important in saccadic response modes, are elicited at the midpoint of simultaneously presented peripheral cue displays (Klein, Christie, & Morris, 2005; Christie, Hilchey, & Klein, 2013). In their experiments stimulus displays were like in our own design, spatially balanced around fixation and the locus of IOR after multiple simultaneous cues was found to be at the midpoint inbetween (even when this was the fixation cross), hence only little IOR could be found for peripheral targets. Although we were using color singleton cues and our stimulus material was carefully balanced regarding its luminance (and should therefore have progressed mainly through the parvocellular pathways; see e.g. Skottun, 2013), the onset of our cue displays (with slight and equivalent luminance increases on all six positions) may have elicited oculomotor IOR by the retinotectal pathway. That is, the luminance balancing of stimuli in combination with the stimulus displays consisting of elements presented on a circle around the fixation cross may have been responsible for part of the lack of IOR in our study. If this interpretation is correct, this could explain the IOR tendencies in the 200 ms conditions of the manual response experiment where IOR would likely be caused by additions of perceptual and oculomotor components (whereas in the saccadic condition oculomotor components may dominate). This could mean the result of our experiment can not be used to argue against Theeuwes disengagement hypothesis, however it does not corroborate it either, since the observed effect was non-significant.

Also this still doesn't explain the complete absence of IOR in 1000 ms CTOA conditions. An interesting thing to notice with regard to this result, may be the different developments of RTs after valid (same position) and invalid (different position) color singletons in the three CTOA levels of the manual and saccadic response experiments. In the manual response experiment we find monotonic RT patterns in the three CTOA conditions (100, 200, 1000 ms) with generally lower but increasing RTs after valid cues ($552 \text{ ms} < 556 \text{ ms} < 563 \text{ ms}$) and higher but decreasing RTs after invalid cues ($580 \text{ ms} > 577 \text{ ms} > 575 \text{ ms}$). In the saccadic response experiment this pattern looks, notwithstanding the expectedly altogether lower RTs, similar for the two short CTOAs (valid: $314 \text{ ms} < 326 \text{ ms}$; invalid: $332 \text{ ms} > 328 \text{ ms}$), but completely different for the longest one (valid: $279 \text{ ms} =$ invalid: 279 ms). This result is in so far surprising as we not only find no IOR here, but instead we find the by far lowest RTs in the saccadic response condition, which as an addition are virtually the same in both validly and invalidly cued trials. A possible explanation for this observation is that this pattern is caused by orienting mechanisms which are at work independently of the spatial orienting system (see e.g. Awh, Belopolsky, & Theeuwes, 2012). Recently evidence has accumulated which suggests that the temporal structure of incoming visual information is used for orienting attention in time (e.g. Girardi, Antonucci, & Nico, 2013; Yashar & Lamy, 2013). This means for our experiment that for example the recognition of a trial as belonging to the 1000 ms condition may have enabled a temporal preparation of responses (probably brought about by implicit learning). Put differently, the use of two short (100 ms, 200 ms) and one long (1000 ms) CTOA conditions may have enabled participants to realize that if the target did not appear after 200 ms it would surely appear at a specific point in time (1000 ms after cue onset) and to prepare their responses or perception accordingly, hence the extraordinarily low RTs in 1000 ms conditions of the saccadic response experiment. Differences between the two experiments may then be modulated by task difficulty or response modality. Such an interpretation would be in line with an extension of the contingent capture account known as the displaywide contingent orienting hypothesis (Gibson & Kelsey, 1998; see also Burnham, 2007), which suggests that virtually all features of a stimulus display (or in

this case the procedure) can be used for orienting attention in a goal directed fashion. It could however also be interpreted as a result of processes considered to be involuntary and stimulus driven like intertrial priming which would then override IOR and therefore be in line with Theeuwes bottom-up account (Rohenkohl, Gould, Pessoa, & Nobre, 2014; Seibold & Rolke, 2014). The question is then how to properly define bottom-up and top-down orienting or whether this distinction makes sense after all. Yet it's important to note that all this reasoning is just speculation and although IOR seems to be modulated by temporal predictability (Gabay & Henik, 2010) there is to best of my knowledge no evidence that IOR would be completely abolished by temporal preparation (e.g. Los, 2004). Therefore although interesting both presented alternative explanations for the lack of IOR in our experiments should be considered no more than hypothesis that may be starting points for future examinations regarding the nature of IOR.

The decisive factor for the lack of IOR in the conducted experiments may be a different one. As was mentioned before, the experiments described in this thesis were part of a series of experiments carried out at our lab and importantly in other circumstances the same stimulus material was, with a little changed procedure, able to elicit IOR speaking against an important role of the stimulus material. In some of those experiments (Ansorge et al., 2013) the in this thesis matching and non-matching cues were rendered relevant or irrelevant by integrating them into a dual task procedure. Critically when a cue's color had to be kept in mind for a later discrimination task IOR could be found even after color singleton cues. The authors therefore concluded that cue relevance is an important factor in the generation of IOR. Since the used stimulus material was virtually the same, this interpretation appears to be the most plausible. It may be that the other discussed factors contributed to an absence of external IOR, but that internal components which have been found to be sufficient for an appearance of IOR (e.g. D. T. Smith, Jackson, & Rorden, 2009; D. T. Smith, Schenk, & Rorden, 2012) were simply missing in our experiments because cues were irrelevant for the task. Together these findings suggest that IOR can not be used as a hallmark of involuntary attentional capture, since it's appearance depends on attentional control settings.

Implications for Future Research

Since this study (complemented by other studies conducted at our lab) has produced evidence for an absence of IOR despite contingent capture after irrelevant color singleton cues, the interpretation of IOR as a hallmark of attentional capture has become more implausible. Instead higher-level components like the relevance of a cue for the task to be solved appear to be crucial for the presence of IOR, strengthening the role of top-down influences in early perceptual processing. Nevertheless the role of oculomotor components of IOR, as discussed in the previous section, requires further examination. If IOR is indeed produced by endogenous and exogenous effects adding up to the full performance cost, this would have to be taken into account in the conception of future experiments examining the conditions which bring about IOR. The same is true for influences of temporal expectation. In this regard it's also important to learn more about the mechanisms responsible for temporal orienting. Are they automatic and a result of intertrial priming or does their appearance depend on conscious perception of the temporal structure in trials?

Another important point is that IOR seems to be a very complex mechanism which is despite a tremendous amount of research only little understood. Besides the points mentioned in this thesis there may be even more factors (e.g. conscious awareness of cues, reward history) which have to be taken into account when reasoning about IOR. It is clear that IOR is, because of it's situatedness on the border between stimulus driven and top-down influenced processing, a phenomenon of high importance for a correct understanding of the mechanisms of visual search and visual perception in general. Considering it's complex nature, computational models (which are increasingly seen as a valuable tool in psychological research; e.g. Fum, Missier, & Stocco, 2007; Farrell & Lewandowsky, 2010) incorporating bottom-up and top-down components could facilitate a better understanding of the interplay of influences present in the phenomenon. The huge body of research conducted in visual perception is in need for overarching theories (e.g. Newell, 1973) and provides an ideal basis for the development of psychologically and biologically plausible computational models.

References

- Alonso, J.-M., & Chen, Y. (2009). Receptive field. *Scholarpedia*, 4(1), 5393. doi: 10.4249/scholarpedia.5393
- Ansorge, U., & Heumann, M. (2003). Top-down contingencies in peripheral cuing: The roles of color and location. *Journal of Experimental Psychology: Human Perception and Performance*, 29(5), 937–948. doi: 10.1037/0096-1523.29.5.937
- Ansorge, U., Priess, H.-W., & Kerzel, D. (2013). Effects of relevant and irrelevant color singletons on inhibition of return and attentional capture. *Attention, Perception, & Psychophysics*, 75(8), 1687–1702. doi: 10.3758/s13414-013-0521-2
- Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences*, 16(8), 437–443. doi: 10.1016/j.tics.2012.06.010
- Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics*, 55(5), 485–496. doi: 10.3758/bf03205306
- Beck, D. M., & Kastner, S. (2007). Stimulus similarity modulates competitive interactions in human visual cortex. *Journal of Vision*, 7(2), 19. doi: 10.1167/7.2.19
- Belopolsky, A. V., & Theeuwes, J. (2010). No capture outside the attentional window. *Vision Research*, 50(23), 2543–2550. doi: 10.1016/j.visres.2010.08.023
- Berlucchi, G. (2006). Inhibition of return: A phenomenon in search of a mechanism and a better name. *Cognitive Neuropsychology*, 23(7), 1065–1074. doi: 10.1080/02643290600588426
- Briand, K. A., Larrison, A. L., & Sereno, A. B. (2000). Inhibition of return in manual and saccadic response systems. *Perception & Psychophysics*, 62(8), 1512–1524. doi: 10.3758/BF03212152
- Burnham, B. R. (2007). Displaywide visual features associated with a search display's appearance can mediate attentional capture. *Psychonomic Bulletin & Review*, 14(3), 392–422. doi: 10.3758/BF03194082
- Burnham, B. R. (2013). Using response time distributions to examine top-down influences

- on attentional capture. *Attention, Perception, & Psychophysics*, 75(2), 257–277. doi: 10.3758/s13414-012-0396-7
- Chica, A. B., Martín-Arévalo, E., Botta, F., & Lupiáñez, J. (2014). The spatial orienting paradigm: How to design and interpret spatial attention experiments. *Neuroscience and Biobehavioral Reviews*, 40, 35–51. doi: 10.1016/j.neubiorev.2014.01.002
- Christie, J., Hilchey, M. D., & Klein, R. M. (2013). Inhibition of return is at the midpoint of simultaneous cues. *Attention, Perception & Psychophysics*, 75(8), 1610–1618. doi: 10.3758/s13414-013-0510-5
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18(1), 193–222. doi: 10.1146/annurev.neuro.18.1.193
- Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research*, 36(12), 1827–1837. doi: 10.1016/0042-6989(95)00294-4
- Dowling, J. (2007). Retina. *Scholarpedia*, 2(12), 3487. doi: 10.4249/scholarpedia.3487
- Dukewich, K. R. (2009). Reconceptualizing inhibition of return as habituation of the orienting response. *Psychonomic Bulletin & Review*, 16(2), 238–251. doi: 10.3758/PBR.16.2.238
- Eckstein, M. P. (2011). Visual search: A retrospective. *Journal of Vision*, 11(5), 14. doi: 10.1167/11.5.14
- Egeth, H. E., Leonard, C. J., & Leber, A. B. (2010). Why salience is not enough: Reflections on top-down selection in vision. *Acta Psychologica*, 135(2), 130. doi: 10.1016/j.actpsy.2010.05.012
- Farrell, S., & Lewandowsky, S. (2010). Computational models as aids to better reasoning in psychology. *Current Directions in Psychological Science*, 19(5), 329–335. doi: 10.1177/0963721410386677
- Folk, C. L., & Remington, R. W. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, 24(3), 847–858. doi: 10.1037/0096-1523.24.3.847

- Folk, C. L., & Remington, R. W. (2006). Top-down modulation of preattentive processing: Testing the recovery account of contingent capture. *Visual Cognition*, 14(4-8), 445–465. doi: 10.1080/13506280500193545
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, 18(4), 1030. doi: 10.1037/0096-1523.18.4.1030
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1993). Contingent attentional capture: A reply to yantis (1993). *Journal of Experimental Psychology: Human Perception and Performance*, 19(3), 682–685. doi: 10.1037/0096-1523.19.3.682
- Fum, D., Missier, F. D., & Stocco, A. (2007). The cognitive modeling of human behavior: Why a model is (sometimes) better than 10,000 words. *Cognitive Systems Research*, 8(3), 135–142. doi: 10.1016/j.cogsys.2007.07.001
- Gabay, S., & Henik, A. (2010). Temporal expectancy modulates inhibition of return in a discrimination task. *Psychonomic Bulletin & Review*, 17(1), 47–51. doi: 10.3758/PBR.17.1.47
- Gibson, B. S., & Amelio, J. (2000). Inhibition of return and attentional control settings. *Perception & Psychophysics*, 62(3), 496–504. doi: 10.3758/bf03212101
- Gibson, B. S., & Kelsey, E. M. (1998). Stimulus-driven attentional capture is contingent on attentional set for displaywide visual features. *Journal of Experimental Psychology: Human Perception and Performance*, 24(3), 699–706. doi: 10.1037/0096-1523.24.3.699
- Gilbert, C. D., & Li, W. (2013). Top-down influences on visual processing. *Nature Reviews Neuroscience*, 14(5), 350–363. doi: 10.1038/nrn3476
- Girardi, G., Antonucci, G., & Nico, D. (2013). Cueing spatial attention through timing and probability. *Cortex*, 49(1), 211–221. doi: 10.1016/j.cortex.2011.08.010
- Godijn, R., & Theeuwes, J. (2004). The relationship between inhibition of return and saccade trajectory deviations. *Journal of Experimental Psychology: Human Perception and Performance*, 30(3), 538–554. doi: 10.1016/j.visres.2003.09.035
- Helmholtz, H. v. (1896). *Handbuch der physiologischen Optik*. Leipzig, Germany: Leopold

- Voss. Retrieved from <https://archive.org/stream/handbuchderphys00kngoog>
- Hooge, I. T. C., Over, E. A. B., van Wezel, R. J. A., & Frens, M. A. (2005). Inhibition of return is not a foraging facilitator in saccadic search and free viewing. *Vision Research*, 45(14), 1901–1908. doi: 10.1016/j.visres.2005.01.030
- Itti, L. (2007). Visual salience. *Scholarpedia*, 2(9), 3327. doi: 10.4249/scholarpedia.3327
- Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, 40(10–12), 1489–1506. doi: 10.1016/S0042-6989(99)00163-7
- Klein, R. M., Christie, J., & Morris, E. P. (2005). Vector averaging of inhibition of return. *Psychonomic Bulletin & Review*, 12(2), 295–300. doi: 10.3758/BF03196375
- Klein, R. M., & Hilchey, M. D. (2011). Oculomotor inhibition of return. In S. P. Liversedge, I. Gilchrist, & S. Everling (Eds.), *The oxford handbook of eye movements* (pp. 471–492). Oxford, England: Oxford University Press.
- Klein, R. M., & Ivanoff, J. (2008). Inhibition of return. *Scholarpedia*, 3(10), 3650. doi: 10.4249/scholarpedia.3650
- Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. *Psychological Science*, 10(4), 346–352. doi: 10.1111/1467-9280.00166
- Krauzlis, R. J., Lovejoy, L. P., & Zenon, A. (2013). Superior colliculus and visual spatial attention. *Annual Review of Neuroscience*, 36. doi: 10.1146/annurev-neuro-062012-170249
- Lamy, D., & Kristjánsson, Á. (2013). Is goal-directed attentional guidance just intertrial priming? A review. *Journal of Vision*, 13(3), 14. doi: 10.1167/13.3.14
- Lamy, D., Leber, A., & Egeth, H. E. (2004). Effects of task relevance and stimulus-driven salience in feature-search mode. *Journal of Experimental Psychology: Human Perception and Performance*, 30(6), 1019–1031. doi: 10.1037/0096-1523.30.6.1019
- Leonard, C. J., & Egeth, H. E. (2008). Attentional guidance in singleton search: An examination of top-down, bottom-up, and intertrial factors. *Visual Cognition*, 16(8), 1078–1091. doi: 10.1080/13506280701580698

- Liao, H.-I., & Yeh, S.-L. (2013). Capturing attention is not that simple: Different mechanisms for stimulus-driven and contingent capture. *Attention, Perception, & Psychophysics*, *75*(8), 1703–1714. doi: 10.3758/s13414-013-0537-7
- Los, S. A. (2004). Inhibition of return and nonspecific preparation: Separable inhibitory control mechanisms in space and time. *Perception & Psychophysics*, *66*(1), 119–130. doi: 10.3758/bf03194866
- Lovejoy, L. P., & Krauzlis, R. J. (2010). Inactivation of primate superior colliculus impairs covert selection of signals for perceptual judgments. *Nature Neuroscience*, *13*(2), 261–266. doi: 10.1038/nn.2470
- Lupiañez, J., Decaix, C., Siéoff, E., Chokron, S., Milliken, B., & Bartolomeo, P. (2004). Independent effects of endogenous and exogenous spatial cueing: Inhibition of return at endogenously attended target locations. *Experimental Brain Research*, *159*(4), 447–457. doi: 10.1007/s00221-004-1963-5
- Lupiañez, J., Martín-Arévalo, E., & Chica, A. B. (2013). Is inhibition of return due to attentional disengagement or to a detection cost? The detection cost theory of IOR. *Psicológica*, *34*(2), 221–252.
- Lupiañez, J., Milán, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics*, *59*(8), 1241–1254. doi: 10.3758/bf03207599
- Mach, E. (1903). *Die Analyse der Empfindungen und das Verhältnis des Psychischen zum Physischen*. Jena, Germany: Gustav Fischer Verlag. Retrieved from <https://archive.org/details/dieanalysederem00machgoog>
- Martinez-Conde, S., Macknik, S. L., & Hubel, D. H. (2004). The role of fixational eye movements in visual perception. *Nature Reviews Neuroscience*, *5*(3), 229–240. doi: 10.1038/nrn1348
- Newell, A. (1973). You can't play 20 questions with nature and win: Projective comments on the papers of this symposium. In W. G. Chase (Ed.), *Visual information processing* (pp. 283–308). Academic Press.

- Niebur, E. (2007). Saliency map. *Scholarpedia*, 2(8), 2675. doi: 10.4249/scholarpedia.2675
- Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, 32(1), 3–25. doi: 10.1080/00335558008248231
- Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology*, 2(3), 211–228. doi: 10.1080/02643298508252866
- Pratt, J., & McAuliffe, J. (2002). Determining whether attentional control settings are inclusive or exclusive. *Perception & Psychophysics*, 64(8), 1361–1370. doi: 10.3758/bf03194778
- Pratt, J., & Neggers, B. (2008). Inhibition of return in single and dual tasks: Examining saccadic, keypress, and pointing responses. *Perception & Psychophysics*, 70(2), 257–265. doi: 10.3758/pp.70.2.257
- Pratt, J., Sekuler, A. B., & McAuliffe, J. (2001). The role of attentional set on attentional cueing and inhibition of return. *Visual Cognition*, 8(1), 33–46. doi: 10.1080/13506280042000018
- Rayner, K., & Castelhamo, M. (2007). Eye movements. *Scholarpedia*, 2(10), 3649. doi: 10.4249/scholarpedia.3649
- Riggs, L. A., Ratliff, F., Cornsweet, J. C., & Cornsweet, T. N. (1953). The disappearance of steadily fixated visual test objects. *Journal of the Optical Society of America*, 43(6), 495–500. doi: 10.1364/JOSA.43.000495
- Rizzolatti, G., & Craighero, L. (2010). Premotor theory of attention. *Scholarpedia*, 5(1), 6311. doi: 10.4249/scholarpedia.6311
- Rohenkohl, G., Gould, I. C., Pessoa, J., & Nobre, A. C. (2014). Combining spatial and temporal expectations to improve visual perception. *Journal of Vision*, 14(4), 8. doi: 10.1167/14.4.8
- Rouder, J. N., & Speckman, P. L. (2004). An evaluation of the vincentizing method of forming group-level response time distributions. *Psychonomic Bulletin & Review*, 11(3), 419–427. doi: 10.3758/bf03196589

- Ruff, C. C. (2013). Sensory processing: Who's in (top-down) control? *Annals of the New York Academy of Sciences*, 1296(1), 88–107. doi: 10.1111/nyas.12204
- Seibold, V. C., & Rolke, B. (2014). Does temporal preparation facilitate visual processing in a selective manner? Evidence from attentional capture. *Acta Psychologica*, 151, 51–61. doi: 10.1016/j.actpsy.2014.05.012
- Skottun, B. C. (2013). On using isoluminant stimuli to separate magno-and parvocellular responses in psychophysical experiments—a few words of caution. *Behavior Research Methods*, 45(3), 637–645. doi: 10.3758/s13428-012-0290-1
- Smith, D. T., Jackson, S. R., & Rorden, C. (2009). An intact eye-movement system is not required to generate inhibition of return. *Journal of Neuropsychology*, 3(Pt 2), 267–271. doi: 10.1348/174866408X324377
- Smith, D. T., Schenk, T., & Rorden, C. (2012). Saccade preparation is required for exogenous attention but not endogenous attention or IOR. *Journal of Experimental Psychology. Human Perception and Performance*, 38(6), 1438–1447. doi: 10.1037/a0027794
- Smith, T. J., & Henderson, J. M. (2011). Looking back at waldo: Oculomotor inhibition of return does not prevent return fixations. *Journal of Vision*, 11(1), 3. doi: 10.1167/11.1.3
- Stigchel, S. V. d., Belopolsky, A. V., Peters, J. C., Wijnen, J. G., Meeter, M., & Theeuwes, J. (2009). The limits of top-down control of visual attention. *Acta Psychologica*, 132(3), 201–212. doi: 10.1016/j.actpsy.2009.07.001
- Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics*, 51(6), 599–606. doi: 10.3758/bf03211656
- Theeuwes, J. (1994). Endogenous and exogenous control of visual selection. *Perception*, 23(4), 429 – 440. doi: 10.1068/p230429
- Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review*, 11(1), 65–70. doi: 10.3758/bf03206462
- Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychologica*, 135(2), 77–99. doi: 10.1016/j.actpsy.2010.02.006

- Theeuwes, J. (2013). Feature-based attention: It is all bottom-up priming. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 368(1628), 20130055. doi: 10.1098/rstb.2013.0055
- Theeuwes, J., & Chen, C. Y. D. (2005). Attentional capture and inhibition (of return): The effect on perceptual sensitivity. *Perception & Psychophysics*, 67(8), 1305–1312. doi: 10.3758/BF03193636
- Theeuwes, J., & Godijn, R. (2002). Irrelevant singletons capture attention: Evidence from inhibition of return. *Perception & Psychophysics*, 64(5), 764–770. doi: 10.3758/BF03194743
- Theeuwes, J., Mathôt, S., & Grainger, J. (2014). Object-centered orienting and IOR. *Attention, Perception, & Psychophysics*. doi: 10.3758/s13414-014-0718-z
- Theeuwes, J., & Van der Burg, E. (2011). On the limits of top-down control of visual selection. *Attention, Perception & Psychophysics*, 73(7), 2092–2103. doi: 10.3758/s13414-011-0176-9
- Theeuwes, J., & Van der Stigchel, S. (2006). Faces capture attention: Evidence from inhibition of return. *Visual Cognition*, 13(6), 657–665. doi: 10.1080/13506280500410949
- Tipper, S. P., Driver, J., & Weaver, B. (1991). Short report: Object-centred inhibition of return of visual attention. *The Quarterly Journal of Experimental Psychology*, 43(2), 289–298. doi: 10.1080/14640749108400971
- Walker, J. (2012). Human saccadic eye movements. *Scholarpedia*, 7(7), 5095. doi: 10.4249/scholarpedia.5095
- Wang, Z., Satel, J., & Klein, R. M. (2012). Sensory and motor mechanisms of oculomotor inhibition of return. *Experimental Brain Research*, 218(3), 441–453. doi: 10.1007/s00221-012-3033-8
- Wilming, N., Harst, S., Schmidt, N., & König, P. (2013). Saccadic momentum and facilitation of return saccades contribute to an optimal foraging strategy. *PLoS Computational Biology*, 9(1), e1002871. doi: 10.1371/journal.pcbi.1002871
- Wolfe, J., & Horowitz, T. (2004). What attributes guide the deployment of visual at-

- tention and how do they do it? *Nature Reviews Neuroscience*, 5(6), 495–501. doi: 10.1038/nrn1411
- Wolfe, J., & Horowitz, T. (2008). Visual search. *Scholarpedia*, 3(7), 3325. doi: 10.4249/scholarpedia.3325
- Wyble, B., Folk, C., & Potter, M. C. (2013). Contingent attentional capture by conceptually relevant images. *Journal of Experimental Psychology: Human Perception and Performance*, 39(3), 861–871. doi: 10.1037/a0030517
- Yashar, A., & Lamy, D. (2013). Temporal position priming: Memory traces of recent experience bias the allocation of attention in time. *Journal of Experimental Psychology: Human Perception and Performance*, 39(5), 1443–1456. doi: 10.1037/a0031231

Zusammenfassung

Rückkehrhemmung (Inhibition of Return) wird als Indikator für unwillkürliche Aufmerksamkeitsverlagerungen nach salienten nicht prädiktiven peripheren Hinweisreizen betrachtet. Während viele Studien Rückkehrhemmung nach Onset-Hinweisreizen finden konnten, sind die experimentellen Hinweise auf Rückkehrhemmung nach Farb-Singleton Hinweisreizen gemischter Natur. Die für diese Abschlussarbeit durchgeführte Untersuchung sollte die Frage klären, ob in solchen Studien die keine Rückkehrhemmung nach Farb-Singleton Hinweisreizen gefunden haben, Eigenheiten des experimentellen Vorgehens für die Abwesenheit von Rückkehrhemmung verantwortlich sind. In einem ersten Experiment wurde mittels einer Variation der örtlichen Hinweisreiz-Prozedur der Befund einer Abwesenheit von Rückkehrhemmung nach Farb-Singletons in einer auf Tastendruck-Antworten basierten Diskriminationsaufgabe repliziert (Gibson & Amelio, 2000). Nach der erfolgreichen Replikation wurden die gleiche Prozedur und die gleichen Stimuli genutzt um zu testen ob eine Veränderung zum vermutlich rückkehrhemmungssensibleren sakkadischen Antwortmodus und einer Detektionsaufgabe sonst verborgene Rückkehrhemmung aufdecken kann. Dies war nicht der Fall. Mögliche Erklärungen für diesen Befund sowie Limitationen der Experimente werden diskutiert. Abschließend werden Implikationen für die Debatte über den Einfluß von Aufmerksamkeit auf die frühe visuelle Verarbeitung aufgezeigt und Vorschläge für zukünftige Studien gemacht.

David Schwenen

Curriculum Vitae

Persönliche Daten

Geburtsort Lingen (Ems), Deutschland
Nationalität Deutsch

Bildungsweg

- 01.-03.2013 **Praktikum**, *Lehr- und Forschungspraxis (Universität Wien)*, Wien.
Mitarbeit an einer Studie zum Präsenzerleben in virtuellen Realitäten
- 2011–2012 **Student Advisor**, *Universität Wien*, Wien.
Einjährige Ausbildung im Rahmen des Student Orientation Tutoriums
- 2011 **Online Kurs**, *Introduction to Artificial Intelligence*.
Einer der ersten auf eine große Zahl Studenten zugeschnittenen Online Kurse basierend auf der Stanford Lehrveranstaltung “Introduction to Artificial Intelligence”
- 2009-2011 **Interview-Tätigkeit**, *L&R Sozialforschung*, Wien.
seit 2006 **Diplomstudium Psychologie**, *Universität Wien*, Wien.
Pflichtwahlfächer: Bildungspsychologie, Klinische Psychologie
Freies Wahlfach (Schwerpunkt): Statistical and Cognitive Modeling
- 02.-08.2006 **Mitarbeiter**, *Wohnheim Herrenkamp (Christopherus-Werk)*, Lingen.
6 monatige Tätigkeit als Mitarbeiter nach dem Zivildienst
- 2005–2006 **Zivildienst**, *Wohnheim Herrenkamp (Christopherus-Werk)*, Lingen.
Unterstützung schizophrener Patienten in einer Langzeit-Wohneinrichtung
- 2002–2005 **Oberstufe & Abitur**, *Gymnasium Johanneum*, Lingen.
Leistungsfächer: Deutsch & Biologie
- 1996–2002 **Mittelstufe**, *Gymnasium Leoninum*, Handrup.
Anschließend Schulwechsel wegen der Entfernung zum Wohnort
- 1992–1996 **Grundschule**, *Grundschule Gauerbach*, Lingen.
Gymnasialempfehlung

Sprachkenntnisse

Deutsch	Muttersprache
Englisch	Sehr gut
Latein	Latinum

Softwarekenntnisse

Office	Microsoft Office
	Libre Office
	LyX
	L ^A T _E X
Statistik	IBM SPSS
	R
	Mathworks MATLAB
	Octave
Grafikerstellung	Inkscape
Sonstiges	Linux